A Study on Enhancing the Properties of Geopolymer Concrete Using Hybrid Fibers

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Abstract: Alkali is present in significant quantities in geopolymer concretes. Due of this, their ductility and flexural strength are also low. The flexural strength of concrete is enhanced by the addition of fibers. Flexural strength has been a challenge for geopolymer concretes, thus researchers have tried using fibers to strengthen them. On the other hand, geopolymer concretes have never before utilized hybrid fibers. This study is an effort to incorporate hybrid fibers in geopolymer concrete to prevent its brittle fracture. Experiments are conducted to learn more about the geopolymer concrete's different mechanical characteristics, and then the settings are fine-tuned. Mechanical qualities of geopolymer concrete are improved by determining the optimal molarity of sodium hydroxide, the optimal ratio of sodium silicate to sodium hydroxide, and the optimal proportion of addition of fibers.

Keywords: Properties, Geopolymer Concrete, Hybrid Fibers, molarity, mechanical properties.

1. INTRODUCTION

Everyone has an innate want to reside in a safe, secure, and pristine setting free from pollution. Cement's demand has skyrocketed as the building industry has expanded, and as a result, manufacturers are cranking out more and more of the stuff. It's a big cause of the planet warming up. When it comes to environmentally friendly building materials, the construction industry is showing a lot of enthusiasm for geopolymer technology, which is part of the concrete technology globe. From the time of the pyramids, people have been trying to figure out how to use this technology. In 1978, Professor Davidovits J. invented the term "Geo-polymer" after discovering that the polymerization process comprises a very rapid chemical reaction under alkaline environment on Si-Al minerals, yielding a three-dimensional polymeric chain and ring structure comprised of Si-O-Al-O links (Anjali Jamale, 2015). As aluminosilicate molecular networks, geopolymers are created when materials containing reactive alumina and silica, and possibly an additional silica source (sodium silicate or amorphous silica), are dissolved in alkaline-activating solutions (sodium or potassium hydroxide) at temperatures below 100 degrees Celsius (Kawade, 2013). The idea behind this geopolymer is that when an alkaline activating solution is added to Al-Si source materials like fly ash or rice husk, a polymerization of the Si-O-Al-O link forms (NaOH or KOH solution with Na_2SiO_3 or K_2SiO_3).

Need of Alternative to Cement

The cement business generates 7% of total CO_2 because burning lime stone releases CO_2 directly and producing one ton of Portland cement releases one ton of CO_2. Calcium carbonate limestone is burned to produce calcium oxide and CO_2. This technique produces 50% of cement emissions. Kiln heating using fossil fuels produces indirect emissions. These fuels emit CO_2. Human-emitted greenhouse gases like CO_2 cause global warming. CO_2 causes 65% of global warming. Cement is a big contributor to global warming; therefore we need to find a safe, durable, and pollution-free substitute (Mulik Sambhaji, 2016).

Geopolymer technology replaces cement with any silica- and alumina-rich substance. Geopolymer concrete may be made from cement substitutes such rice husk ash, fly ash, and GGBS. Fly ash disposal and abundance are important challenges. Coal-fired power stations produce fly ash. It is considered garbage and its disposal has caused several environmental and ecological issues (Rahman, 2021).

Power generation is crucial for emerging nations like India. Fly ash output rises. The cement sector emits roughly 7% of world CO_2. Fly-ash reduces clinker use and greenhouse gas emissions. Fly ash instead of cement reduces manufacturing costs and improves quality. Cement manufacturing and delivery costs put strain on cement industry finances. Fly ash may be used in cement and clinker manufacturing due to environmental awareness and laws. Cement is crystalline, while fly ash is glassy owing to quick cooling. Fly ash has less CaO than Portland cement (Timakul, 2016).

1.2. Applications of Geopolymer Concrete

Geopolymer concrete is used like cement concrete. This content has not yet been utilized for other purposes. Geopolymer concrete uses are below (Zhao, 2019):

- Geopolymer concrete is promising for bridge precast structures and decking. Precast geopolymer concrete works well.

- Precast bricks, pavers, and pipes are among possible uses.

2. RESEARCH METHODOLOGY

To meet I.S. regulations, hybrid fiber percentages are tested. Present work has three stages. Research begins on fiberless geopolymer concrete. NaOH molarity is 8–24 mol. The sodium silicate-sodium hydroxide ratio is 1, 1.5, or 2. Steel crimped fibers with aspect ratios 60, 70, and 100 are added to geopolymer concrete in the second stage of study. Geopolymer concrete uses polypropylene and basalt fibers individually. Fiber hybridization occurs in the third research step. First, steel fibers with aspect ratios 60, 70, and 100 hybridized with polypropylene fibers. Geopolymer concrete contains 60-aspect-ratio steel fibers hybridized with basalt fibers.

Ingredients of Geopolymer Concrete

Geopolymer concrete in this study has the following ingredients:

- Fly ash
- Fine Aggregates
- Coarse Aggregates
- Alkaline Solutions
- Water
- Fibers

The Geopolymer Concrete Mix Design

Researchers offered geopolymer concrete mix design recommendations. The reference mix for plain geopolymer concrete follows Dr. Patankar S. V.'s instructions and I.S. 10262-2009 and I.S. 456-2000. Mix design and three-part research are done. First, ordinary geopolymer concrete specimens are examined for different sodium silicate-to-sodium hydroxide ratios. First portion alkaline solution-fly ash ratio is 0.35. Second portion optimal mix for 13 M NaOH. Geopolymer concrete's second phase adds fibers in variable percentages. Second portion alkaline solution to fly ash ratio is 0.40 for workability. Geopolymer concrete contains hybrid fibers. Steel polypropylene and steel basalt hybridize. Alkaline solution-to-fly ash ratio is 0.45.

Preparation of Specimen

Labs measure components, prepare alkaline solutions, and create geopolymer concrete. Cast examples from fresh geopolymer concrete of various compositions. Cast cubes, cylinders, and beams test mechanical qualities.

Measurement of Ingredients: Digital balances assess fly ash, sand, coarse aggregate (12.5 mm and 20 mm), and other fibers. One-liter cylinders measure water.

Preparation of Alkaline Solution: Water dissolves sodium hydroxide flakes to make solution. Table 1 shows sample computation. 97% purity flakes. To cool the exothermically heated sodium hydroxide solution, it is made a day before concrete batching. Measure and mix the flakes carefully. Before concrete batching, sodium silicate and sodium hydroxide were combined.

3. MATERIEL AND METHODS

3.1. Ion-Exchange Membranas

The work used heterogeneous IEM produced by Schekinoazot (Russia), being a cation exchange membrane (MK-40) and an anion exchange membrane (MA-41), both with a working area of 3.14 cm2. Before each experiment, the membranes were immersed in the working solutions for 24 hours. Some of the main characteristics of the membranes are shown in Table 1.

Table 1: Mass of NaOH as per Molarity

Sr. No	Molarity (M)	Mass of NaOH (g)
1	8	320
2	10	400
3	12	480
4	13	520
5	14	560
6	16	640
7	24	840

3.2. Mixing of Concrete: Accurately measured and dry-mixed components after mixing, the dry concrete mix is homogenous. Dry mixture, Alkaline solution (sodium hydroxide + sodium silicate) is weighed in plastic bucket and put into dry mix. Add water as needed.

Details of Test Specimens for Tests on Hardened Concrete

After oven removal, specimens are examined at 3, 7, and 28 days. Geopolymer Concrete preparation with and without fibers.

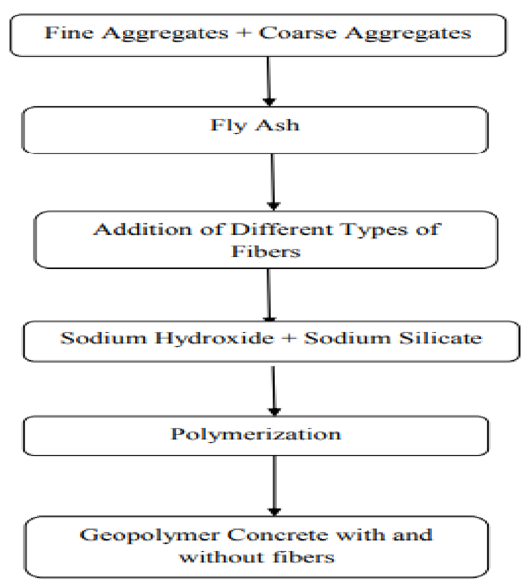

Figure 1: Preparation of Geopolymer Concrete

Testing of specimens

Indian Standard examines fresh and hardened concrete:

- Fresh Concrete Test: Flow table test (IS: 1199- 1959)
- Hardened Concrete Test
- Non Destructive Testing
- Electrical Conductivity test on concrete

Results: Three steps merge three components of this research. In the first step, NaOH molarities are 8M, 10M, 12M, 13M, 14M, 16M, and 24M, while Sodium Silicate to Sodium Hydroxide ratios are 1, 1.5, and 2. In the second stage of study, molarity is optimized for NaOH concentration and Sodium Silicate to Sodium Hydroxide ratio, and three fiber kinds are added to geopolymer concrete. Geopolymer concrete gets hybrid fibers in step three. Three steps provide distinct results, which are briefly addressed.

Compressive Strength of plain GPC with varying molarity and varying ratio of $Na_2SiO_3/NaOH$

Plain geopolymer concrete with different molarities of sodium hydroxide and ratios of sodium silicate to sodium hydroxide has different compressive strengths. 8M, 10M, 12M, 13M, 14M, 16M, and 24M sodium hydroxide concentrations. Sodium silicate-to-sodium hydroxide ratios are 1, 1.5, and 2.

Regression analysis of plain GPC strength data:

Statistically analyzing plain GPC strength with different Na_2SiO_3 to NaOH ratios and molarities. Table 2 shows analysis. Variation is nearly linear.

Table 2: Regression analysis for plain geopolymer concrete of 13 M NaOH concentration and for varying Ratio of $Na_2SiO_3/NaOH$

Molarity	$Na_2SiO_3/NaOH$	Period	Compressive Strength	Regression Equation	R^2
13	1.0	3 Days	27.99	$y = 0.81x^2 - 0.35x + 27.53$	1.0
	1.5		30.07		
	2.0		33.77		
	1.0	7 Days	35.40	$y = 0.745x^2 + 0.575x + 34.08$	1.0
	1.5		38.21		
	2.0		42.51		
	1.0	28 Days	40.20	$y = 0.475x^2 + 2.665x + 37.06$	1.0
	1.5		44.29		
	2.0		49.33		

Compressive Strength of Geopolymer Concrete with Hybrid Fibers

Geopolymer concrete receives two fiber kinds in the third round of study. Steel is rigid while polypropylene is soft. Another combination is steel (stiff) and basalt (soft). Bentur and Mindess say hybridization enhances first fracture stress and ultimate strength by using a stronger and stiffer fiber. The post-cracking zone's toughness and strain capacity are increased by the second fiber type's flexibility and ductility. They recommend a hybrid reinforcement using a smaller fiber to bridge microcracks. Crack growth can be inhibited. The bigger fiber can stop macro fractures.

Table 3: Compressive Strength of Geopolymer Concrete for hybrid fibers SP I

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SP I -1	60	0.8	0.2	49.33	55.1	58.21
2	SP I-2	60	0.6	0.4	42.96	46.22	50.21
3	SP I -3	60	0.4	0.6	31.4	35.55	39.1
4	SP I-4	60	0.2	0.8	26.81	29.62	32.28

The initial combination SP I (0.8 % Crimped Steel and 0.2 % Polypropylene) has the highest compressive strength. Three blends have lower compressive strength. Compressive strength is greatly lowered for SP I-4 mix. Fourth kind had low workable mix and fiber flocculation at one point. But cube specimen failure delayed testing. All four mixes showed no brittle failure, however the dial gauge needle sometimes stopped moving for a few minutes. Hybridization of steel Polypropylene displays cohesive mix for first type and non-cohesive mix for rest. Fly ash and more water make the fourth combination workable.

Table 4: Compressive Strength of GPC for hybrid fibers SP II

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SP II -1	70	0.8	0.2	48.14	54.07	56.88
2	SP II-2	70	0.6	0.4	38.96	44.29	47.7
3	SP II -3	70	0.4	0.6	32.14	35.88	38.51
4	SP II-4	70	0.2	0.8	24.88	27.55	30.36

The initial blend, SP II-1 Crimped Steel Fibers of A.R. 70, 0.8 % + Polypropylene Fibers, 0.2 %, has the highest compressive strength. Hybridization reduces compressive strength relative to SP I mixtures. SP II-3, SP II-4 combines flocculate fibers. Honeycombing specimens reduced compressive strength. This nature requires 5% more fly ash.

Table 5: Compressive Strength of GPC for hybrid fibers SP III

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene%	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SP III -1	100	0.8	0.2	47.55	51.25	54.22
2	SP III-2	100	0.6	0.4	36.77	42.36	46.96
3	SP III -3	100	0.4	0.6	31.257	34.21	37.18
4	SP III-4	100	0.2	0.8	22.21	25.47	29.47

For the initial mix SP III -1 (Crimped Steel Fibers of A.R. 100, 0.8 % + Polypropylene, 0.2 %), geopolymer concrete compressive strength is higher. Other mixtures diminish compressive strength. SP I and SP II hybridization have higher compressive strength than SP III. When combined with polypropylene fibers (SP III), long Crimped steel fibers with aspect ratio 100 flocculated in considerable quantities. Non-uniform fiber distribution makes mix less workable. Geopolymer concrete compressive strength decreases

Table 6: Compressive Strength of GPC for hybrid fibers SB

Sr. No.	Notation	Aspect Ratio	Steel %	Basalt %	Compressive Strength (MPa)		
					3 Days	7 days	28 Days
1	SB 1	60	0.8	0.2	51.35	56.73	59.25
2	SB 2	60	0.6	0.4	43.85	47.88	53.03
3	SB 3	60	0.4	0.6	33.47	38.36	41
4	SB 4	60	0.2	0.8	27.99	29.32	34.51

Table 6 shows hybrid fiber cube specimens' compressive strength. The initial blend SB I Crimped Steel Fibers of A.R. 60, 0.8 % + 0.2 % Polypropylene Fibers has the highest compressive strength. Steel basalt hybridization produces a cohesive composite with higher compressive strength than steel polypropylene. 59.25 MPa compressive strength exceeds all combinations.

Split Tensile Strength of Plain Geopolymer Concrete with varying molarity and varying ratio of Na2SiO3/NaOH

Cylinders are split-tensile tested. After 28 days on plain geopolymer concrete, cylinders are tested for NaOH concentrations from 8 to 24 molar and sodium silicate to sodium hydroxide ratios of 1, 1.5, and 2. Table 7 shows the findings.

Table 7: Split Tensile Strength for Plain Geopolymer Concrete

Sr. No.	Molarity	Na2SiO3/NaOH	Split Tensile Strength in MPa
1	8	1	3.18
		1.5	3.909
		2	4.375
2	10	1	3.492
		1.5	4.137
		2	4.822
3	12	1	3.862
		1.5	4.647
		2	5.331
4	13	1	3.942
		1.5	5.4
		2	5.797
5	14	1	3.899
		1.5	4.666
		2	5.346
6	16	1	3.774
		1.5	4.463
		2	5.285
7	24	1	3.302
		1.5	4.079
		2	4.805

Split tensile strength for varying sodium silicate to sodium hydroxide ratios and molarities of sodium hydroxide. Split tensile strength decreases with 13 Molar NaOH concentration. The greatest split tensile strength is 2 sodium silicate to sodium hydroxide. Cohesive mix with 13 Molar NaOH concentration gives maximum split tensile strength.

Split Tensile Strength of Geopolymer Concrete with addition of Hybrid Fibers

SP I, SP II, SP III, and SB hybridizations exist. Hybrid fibers are added to geopolymer concrete using 13 Molar NaOH and 2 sodium silicate to sodium hydroxide ratio. All mixtures use 0.45 alkaline solutions to fly ash.

Table 8: Split Tensile Strength of GPC with Hybrid fibers using Steel (60) and Polypropylene

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Split Tensile Strength in MPa
1	SP I -1	60	0.8	0.2	9.23
2	SP I-2	60	0.6	0.4	6.972
3	SP I -3	60	0.4	0.2	5.478
4	SP I-4	60	0.2	0.8	4.256

First-mix split tensile strength is 9.23 MPa. Due to reduced workability of geopolymer concrete, split tensile strength is highest for SP I 0.8 % crimped steel + 0.2 % polypropylene. Lowered flow reduced split tensile strength.

Table 9: Split Tensile Strength of GPC with hybrid fibers using Steel (70) and Polypropylene

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Split Tensile Strength in MPa
1	SP II -1	70	0.8	0.2	9.3
2	SP II-2	70	0.6	0.4	7.067
3	SP II -3	70	0.4	0.2	5.369
4	SP II-4	70	0.2	0.8	4.11

The initial mix SP II -1 Crimped steel fibers of A.R. 70, 0.8 % +Polypropylene 0.2 % have the highest split tensile strength. SP II's first two mixes are stronger than SP I's. The remaining two SP II blends have lower spilt tensile strength. Longer fibers hybridized with polypropylene fibers enhance split tensile strength up to 0.4%, after which the combination becomes less workable and split tensile strength decreases.

Table 10: Split Tensile Strength of GPC with hybrid fibers using Steel (100) and Polypropylene

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Split Tensile Strength in MPa
1	SP III -1	100	70	0.8	9.96
2	SP III-2	100	70	0.6	8.097
3	SP III -3	100	70	0.4	4.977
4	SP III-4	100	70	0.2	4.406

SP III-1 mix has the highest split tensile strength. Three mixes—SP III–2, SP III–3, and SP III–4—reduce split tensile strength. For SP III–4, mix was less workable and cylinders honeycombed. Split tensile strength decreases significantly.

Table 11: Split Tensile Strength of GPC with hybrid fibers using Steel (60) and Basalt

Sr. No.	Notation	Aspect Ratio	Steel %	Polypropylene %	Split Tensile Strength in MPa
1	SB 1	60	0.8	0.2	9.024
2	SB 2	60	0.6	0.4	7.16
3	SB 3	60	0.4	0.2	5.24
4	SB 4	60	0.2	0.8	3.83

The first blend SB 1 Crimped Steel fiber of A.R. 70, 0.8 % + 0.2 % Basalt fibers has the highest split tensile strength, whereas the other three mixes have lower strengths. The mix was workable and stronger than SP mixes.

Flexural Strength of Plain GPC with varying molarity and varying ratio of Na2SiO3/NaOH

Flexural Strength measures concrete tensile strength. Beams undergo flexural strength testing. After 28 days, specimens are examined and findings are reported in Table 12 for plain geopolymer concrete for 8 Molar to 24 Molar NaOH concentrations and sodium silicate to sodium hydroxide ratios of 1, 1.5, and 2 to discover the optimal NaOH concentration and ratio.

Table 12: Flexural Strength for Plain Geopolymer Concrete

Sr. No	Molarity	Na2Sio3/NaOH	Flexural Strength in N/mm2
1	8	1	5.511
2		1.5	6.11
3		2	7.056
4	10	1	6.051
5		1.5	6.693
6		2	7.165
7	12	1	6.903
8		1.5	7.961
9		2	8.423
10	13	1	7.476
11		1.5	8.191
12		2	9.038
13	14	1	7.338
14		1.5	8.071
15		2	8.37
16	16	1	6.746
17		1.5	7.263
18		2	7.767
19	24	1	6.041
20		1.5	7.263
21		2	5.811

Flexural strength peaks at 13 Molar NaOH. Maximum ratio is 2 sodium silicate to sodium hydroxide. Flexural strength decreases at 13 Molar NaOH. Polymerization decreases strength at 16 and 24 Molar NaOH concentrations. For further study13, molar NaOH concentration is finished using a 2:1 sodium silicate to sodium hydroxide ratio.

Flexural Strength of Geopolymer Concrete with Hybrid Fibers

Flexural strength of geopolymer concrete for four hybridizations—SP I, SP II, SP III, and SB is developed and described here.

Table 13: Flexural Strength of GPC with Hybrid Fibers Using Steel (60) and Polypropylene

Sr. No.	Type	Molarity	% Steel	% Polypropylene	28 Days
1	SP I -1	13	0.8	0.2	13.38
2	SP I -2		0.6	0.4	10.82
3	SP I -3		0.4	0.6	10.26
4	SP I - 4		0.2	0.8	7.3

The blend of 0.8 percent crimped steel fibers of aspect ratio 60 and 0.2 percent polypropylene fibers has the highest flexural strength. Flexural strength decreases with other mixtures. Fiber dispersion causes flexural weakness. Due to poorer workability, fourth mix reduces flexural strength further.

Table 14: Flexural Strength of GPC with Hybrid Fibers Using Steel (70) and Polypropylene Fibers

Sr. No.	Type	Molarity	% Steel	% Polypropylene	28 Days
1	SP II -1	13	0.8	0.2	13.8
2	SP II -2		0.6	0.4	11.42
3	SP II -3		0.4	0.6	10.54
4	SP II - 4		0.2	0.8	7.72

SP II mixtures have higher flexural strength than SP I. SP II mixes had 3.03, 5.25, 2.65%, and 5.44 percent more flexural strength than SP I mix.

Table 4.15: Flexural Strength of GPC with Hybrid Fibers Using Steel (100) and Polypropylene

Sr. No.	Type	Molarity	% Steel	% Polypropylene	28 Days Flexural Strength, MPa
1	SP III -1	13	0.8	0.2	14.32
2	SP III -2		0.6	0.4	12.56
3	SP III -3		0.4	0.6	10.7
4	SP III- 4		0.2	0.8	7.86

SP III mixes had 24.58 %, 9.075%, 1.50%, and 1.78% higher flexural strength than SP II mixes. Flexural strength increases more for first two mixes but less for last two owing to less cohesive mix.

Table 16: Flexural Strength of GPC with Hybrid Fibers Using Steel (60) and Basalt

Sr. No.	Type	Molarity	% Steel	% Basalt	28 Days Flexural Strength, MPa
1	SB 1	13	0.8	0.2	12.4
2	SB 2		0.6	0.4	13.62
3	SB 3		0.4	0.6	12.24
4	SB 4		0.2	0.8	11.2

The second blend of crimped steel fibers of aspect ratio 60 and basalt fibers has the highest flexural strength. The last two blends also lose strength. All mixes had fiber dispersion. Flexural strength is improved with steel-basalt. Steel polypropylene is softer than basalt.

Non Destructive Testing on Geopolymer Concrete with Hybrid Fibers

Ultrasonic Pulse Velocity and Rebound Hammer Test perform NDT on hybrid fiber GPC.

Table 17: NDT on GPC with hybrid fibers by Ultrasonic Pulse Velocity for SP I

Sr. No.	Type	% Steel	% Polypropylene	Time in Second	UPV (km/Sec)	Concrete Quality
1	SP I -1	0.8	0.2	27	5.55	Excellent
2	SP I-2	0.6	0.4	36	4.16	Good
3	SP I-3	0.4	0.6	48	3.125	Medium
4	SP I- 4	0.2	0.8	57	2.63	Doubtful

The first kind using Crimped Steel Fibers of 60 aspect ratio and polypropylene fibers takes less time. It reduces wave obstacles.

Table 18: NDT on GPC with hybrid fibers by Ultrasonic Pulse Velocity for SPII

Sr. No.	Type	% Steel	% Polypropylene	Time in Second	UPV (km/ Sec)	Concrete Quality
1	SP II -1	0.8	0.2	31	4.83	Excellent
2	SP II-2	0.6	0.4	41	3.66	Good
3	SP II-3	0.4	0.6	51	2.94	Doubtful
4	SP II- 4	0.2	0.8	63	2.38	Doubtful

Ultrasonic pulse velocity is 4.94 Km/Sec for the initial mix SP-II (Crimped Steel Fibers of aspect ratio (70) 0.8 % + Polypropylene 0.2 %). Concrete's dense. Concrete is clear.

Table 19: NDT on GPC with Hybrid Fibers by Ultrasonic Pulse Velocity for SP III

Sr. No.	Type	% Steel	% Polypropylene	Time in Second	UPV (Km/ Sec)	Concrete Quality
1	SP III -1	0.8	0.2	43	3.48	Good
2	SP III-2	0.6	0.4	52	2.88	Doubtful
3	SP III-3	0.4	0.6	67	2.23	Doubtful
4	SP III- 4	0.2	0.8	79	1.89	Doubtful

First mix with ultra-sonic pulse velocity 3.61 takes less time. Concrete is high-quality. Concrete is void-free.

Table 20: NDT on GPC with hybrid fibers by Ultrasonic Pulse Velocity for SB

Sr. No.	Type	% Steel	% Basalt	Time in Seconds	UPV (Km/Sec)	Concrete Quality
1	SB 1	0.8	0.2	25	6.0	Excellent
2	SB 2	0.6	0.4	34	4.4	Good
3	SB 3	0.4	0.6	45	3.33	Medium
4	SB 4	0.2	0.8	54	2.77	Doubtful

Ultrasonic pulse velocity for first and second mixes exceeds 4.5 Km/sec. These two mixtures produce high-quality concrete. Fourth kind of concrete has lower ultrasonic velocity, showing skepticism.

Table 21: NDT on GPC using hybrid fibers by Rebound Hammer for SP I

Sr. No.	Type	Aspect Ratio of Steel	% Steel	% Polypropylene	Compressive Strength in MPa
1	SP I-1	60	0.8	0.2	59
2	SP I-2	60	0.6	0.4	52.73
3	SP I-3	60	0.4	0.6	41.26
4	SP I-4	60	0.2	0.8	32.56

Rebound hammer for SP I combines compressive strength of geopolymer concrete. The initial mix had the highest compressive strength since it was workable and fibers bonded with concrete. Second mix is weaker. Workability and cohesiveness were reduced in the third and fourth mixes, reducing compressive strength.

Table 22: NDT on GPC using hybrid fibers by Rebound Hammer for SP II

Sr. No.	Type	Aspect Ratio of Steel	% Steel	% Polypropylene	Compressive Strength in MPa
1	SP II-1	70	0.8	0.2	58.1
2	SP II-2	70	0.6	0.4	50.43
3	SP II-3	70	0.4	0.6	41.4
4	SP II-4	70	0.2	0.8	32.23

SP II geopolymer concrete rebound hammers compressive strength. Cohesive mix and matrix consolidation around fibers gave SP II -1 the highest compressive strength. Compressive strength diminishes with increasing polypropylene fiber hybridization with steel fibers.

Table 23: NDT on GPC using hybrid fibers by Rebound Hammer for SP III

Sr. No.	Type	AspectbRatio of Steel	% Steel	% Polypropylene	Compressive Strength in MPa
1	SP III-1	100	0.8	0.2	55.46
2	SP III-2	100	0.6	0.4	47.26
3	SP III-3	100	0.4	0.6	38.83
4	SP III-4	100	0.2	0.8	30.066

For SP III Crimped Steel Fibers (100) and Polypropylene Fibers. Specimens were not smooth. The initial mix has the highest compressive strength. Longer steel strands hybridize poorly with polypropylene fibers.

Table 24: NDT on GPC using hybrid fibers by Rebound Hammer for SB

Sr. No.	Type	Aspect Ratio of Steel	% Steel	% Polypropylene	Compressive Strength in MPa
1	SB 1	60	0.8	0.2	61.24
2	SB 2	60	0.6	0.4	54.31
3	SB 3	60	0.4	0.6	42.16
4	SB 4	60	0.2	0.8	33.55

Steel-basalt mixes with aspect ratio 60 crimped steel fibers and basalt fibers provide the highest compressive strength. Steel basalt hybridization produced cohesive steel basalt fibers with better compressive strength than steel polypropylene fibers. Steel basalt hybridization produced smooth specimens.

Table 25: Electrical Conductivity Test on GPC using hybrid fibers SB

TYPE	AC (Ωm)	DC (Ωm)
SB -I	0.01127	0.01023
SB - II	0.00868	0.00724
SB - III	0.005086	0.00416
SB - IV	0.004034	0.002051

Increasing polypropylene fiber content and decreasing crimped steel fiber content reduces electrical conductivity. All combinations have minimal electrical conductivity.

CONCLUSION

Infrastructure development is accelerating. Construction area increases greatly. Society must consider carbon dioxide-reducing cement alternatives to control global warming. GGBS might replace cement in geopolymer concrete. Lime concentration is also significant for partial cement replacement to lower geopolymer concrete curing temperatures below 60 °C. Chemical production is crucial since NaOH molarity and concentration affect strength. Geopolymer concrete cubes with hybrid fibers are rebound-hammered. Rebound hammer tests outperform concrete testing machines. SB mixes outperform SP I, SP II, and SP III mixes. First-type mixtures had the highest compressive strength in all four hybridizations. New technology is needed to make this concrete chemical-friendly. To discover the best fiber composition, polypropylene, basalt, and steel fibers can be hybridized. Glass fibers can hybridize with other fibers in geopolymer concrete.

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DOI: https://doi.org/10.15379/ijmst.v10i3.3380